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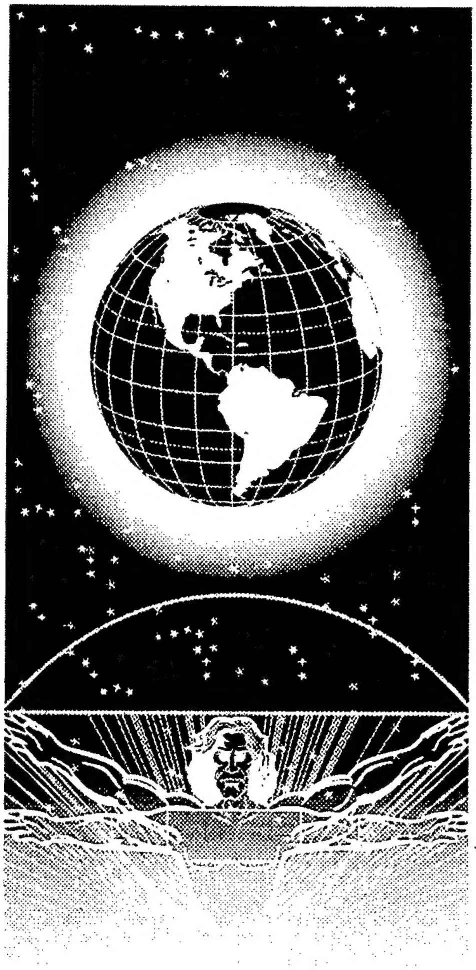

# UNITED STATES AIR FORCE
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# Assessment of Composite Hazards at Crash Sites: Industrial Hygiene Field Guidance For Bioenvironmental Engineers

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Advanced composite material (ACM) use in the military and private sector is increasing. As a result, the personnel responding to a crash site should be able to assess the hazard and determine a category of high or low exposure risk. This assessment will take into consideration: visual assessment, duration and location of fire, physical damage, aircraft type/quantity of composite material, terrain and environmental conditions, phase of recovery and type of crash. Personal Protective Equipment (PPE) required to conduct the site clean up will be directed after site evaluation.

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## I INTRODUCTION - HAMMER INTEGRATED PROCESS TEAM (IPT)

a. The Hazardous Aerospace Material Mishap Emergency Response (HAMMER) program is addressing safety and health issues related to aerospace vehicle mishap response, investigation, recovery, clean-up and disposal. The goals of the HAMMER program include identification and inventory of all hazardous aerospace materials (HAM) on Air Force weapon systems, and to ensure the Air Force has procedures in-place to protect personnel from safety and health hazards associated with these mishaps. The following summarizes some of the completed efforts by the HAMMER IPT:

1. Consolidated List of Hazardous Aerospace Materials: The most complete list of hazardous aerospace materials (HAM) currently in existence is in T.O. 00-105E-9, Aircraft Emergency Rescue Information {maintained by Headquarters Air Force Civil Engineer Support Agency (AFCESA)}. The Industrial Hygiene (IH) Flight is currently working with AFCESA and Aeronautical Systems Center to identify the locations and quantities of all HAM on current and future DoD weapon systems. To view the most complete list of HAM currently available, reference T.O. 00-105E-9 posted at the following web address: http://137.244.215.33/ti/tilta/documents/to00-105E-9.htm

2. Hazardous Aerospace Materials in Aircraft Mishaps for On-Scene Commanders and Emergency Responders: AFIERA's IH Flight produced a two-page pamphlet to assist Commanders and emergency responders in assessing potential hazards and to minimize risk for the on- and off-scene personnel. The guide is located at the following web address: https://www.afms.mil/AFIERA/rsh/IndustrialHygiene/hammerguidance/HAZARDOUS_AEROSPACE_MATERIALS_IN_AIRCRAFT_MISHAPS/pdf

3. Aircraft Mishap Investigation and Prevention (AMIP) Course: AFIERA's IH Flight personnel produced and routinely presents a briefing for students attending the AMIP course. The course prepares flight surgeons, aerospace physiologists, and aviation psychologists to assist with aircraft accident investigations. The purpose of the briefing is to inform the students about the types of hazards they may encounter when responding to a aircraft mishap. Copies of the briefing can be located at the following web address: https://www.afms.mil/AFIERA/RSH/IndustrialHygiene/hammer_presentations.html

4. Burn Study/Actual Crash Site Experience: As part of the HAMMER program, a large-scale aircraft burn study was conducted in September 2000. Multiple burns of large composite (graphite/epoxy) boxes were conducted. Aircraft recovery crews simulated recovery procedures to determine composite fiber and chemical exposure levels. The sampling results from the tests, along with other previous sampling efforts, were used to determine appropriate protective equipment and respiratory protection at mishap sites. The burn study final report can be found at the following web address: https://www.afms.mil/AFIERA/RSH//IndustrialHygiene/hammer.html

**II REPORTED CRASH RECOVERY ILLNESSES:** This issue became important due to reported cases of illnesses and injuries occurring while working at a crash site. The sources of the cited incidents are often unsupported by formal documentation or may be unconfirmed. In the late 1980s, a Navy F-18 fighter plane crashed on Santa Catalina Island. Two search and rescue personnel were exposed to ash and debris and experienced persistent reduced breathing capacity and heightened reactivity to histamine challenge. It is unclear as to the extent of personal protective equipment (PPE) worn by search and rescue personnel. In 1990, a Royal Air Force (RAF) GR.5 Harrier mishap occurred in Denmark. The RAF recovery team reported eyes, respiratory, and skin irritation and sore throats. The firefighters did not report similar complaints, but again it is unclear as to the amount of PPE the recovery workers were using. However, it was reported that following this incident the RAF imposed more stringent PPE requirements. In 1997, after responding to a USAF F-117A mishap, 22 Baltimore area firefighters reported complaints of labored breathing, eye and skin irritation, nausea, and headaches.

**III SOURCES OF EXPOSURE:** The smoke stream contains a mixture of gases, vapors, and particulate matter. The nature of the gases and vapors generated during a fire depends on the composition of the burning materials and the fire growth rate. Broadly classified, polycyclic aromatic hydrocarbons (naphthalene), nitrogen-containing aromatics (aniline), and phenol-based organic compounds have been detected during studies of composite material combustion byproducts. Fire fighting personnel may be exposed to toxic gases and particulates while fighting the fire or when performing rescue operations. Recovery team members may be exposed to particulate material when aircraft parts are being moved or modified by cutting, breaking, twisting, or hammering. As parts are disturbed, composite particulate material may become airborne and further distributed around the site. Since the fibers can penetrate personal protective equipment, splinters to hands or other areas of the skin may occur. Skin or eye irritation is highly likely for an unprotected worker.

## IV ACTUAL AND SIMULATED CRASH SITE EXPOSURE ASSESSMENTS

a. Although the subject of exposures during crash site operations has received a renewed interest, it is important to recognize that there has been a significant effort already to quantify these exposures. A review of these efforts is appropriate to put these exposures into perspective. While the fiber exposure has received the greatest attention, a review of the previous work clearly demonstrates that the exposure levels are low (as compared to the OEL of 1 fiber/cubic centimeter). The preferred fiber sampling method is NIOSH Method 7400 *Asbestos and Other Fibers*, which has been used in seven of the nine events. (See the Air Sampling section for discussion of preferred fiber sampling methods.) The following are summaries of nine crash scenarios that included sampling efforts to quantify exposures to Advanced Composite Material (ACM) between 1986 and 2000. A brief description of the scenario and sampling methodology is given. Tables 1 and 2 provide the results of the minimum to maximum concentrations measured for dust and fibers, respectively.

b. Air sampling was conducted to characterize personnel exposures to particulates after the crash and burn of an aircraft with 590 kg of carbon fiber composites.[1] The F/A-18 crashed in a desert bombing range north of Yuma, Arizona. Air samples were analyzed via gravimetric

analysis and optical microscopy. Optical Microscopy samples were collected on 0.8-µm mixed cellulose ester filters (MCEFs) in open-face cassettes. Gravimetric samples were collected on previously prepared 5-µm pore size polyvinyl chloride (PVC) filters. Personal cascade impactors were also used. Sampling was performed approximately 30 hours after the crash. Soon after the mishap occurred and before the sampling began, polyacrylic acid fixative was applied to larger debris to lessen fiber release. The day after the crash (the crash site had not been disturbed and a slight breeze blew along the area) air samples were taken. On the $4^{th}$ day (also a windy day) personnel A and B were performing recovery procedures (sorting through wreckage and cutting into metal). Personnel C was the primary mishap investigator and was turning pieces of wreckage over and kicking through debris. On the $6^{th}$ day the site was remediated; the aircraft was buried at the site. Personnel D operated the earthmover to open a trench, place materials in the trench, and then close the trench. Person E directed and assisted person D. Area samples were also collected. The majority of the samples were well below the Navy's recommended exposure limits, the Short-Term Exposure Limit (STEL) of 7 $mg/m^3$ and Time-Weighted Average (TWA) of 3.5 $mg/m^3$. Only three samples were above the Navy STEL of 7.5 $mg/m^3$ (Personnel C, D, and E) but these results were of total dust, which included significant amounts of airborne earth.

c. On 12 January 1987, an AV-8B aircraft mishap at the Marine Corps Air Station, Cherry Point, North Carolina, prompted a Navy Environmental Health Center Industrial Hygienist to conduct a comprehensive occupational health survey of the aircraft accident investigation and cleanup (13-17 January 1987).[2] The AV-8B contains 1,317 lbs. or 26% of composites. The Industrial Hygienist collected airborne and bulk samples. Sixty firefighters along with crash and rescue personnel responded to a grass and fuel fire from the aircraft accident. These personnel applied floor wax to larger pieces of wreckage. Two individuals handled spill control by building a dike around the aircraft fuselage to contain any leaking. Prior to Reclamation bulk samples were collected. Results indicated an order of magnitude increase for chromium, and levels of Acenaphthylene (PAH) elevated in 3 of 4 samples when compared to raw graphite cloth. The source of chromium was undetermined; however, the PAH source is believed to have originated from the jet fuel used in the aircraft (JP-5). The Naval Safety Center accident investigator and Emergency Reclamation Team (ERT) proceeded with retrieval of pertinent aircraft components by digging, moving, and collecting components. Sampling during these activities was conducted on 15 January 1987 using Dupont P2500 pumps at 2.0 liters per minute with open-faced MCEFs (37-mm and 0.8 µm pore size). Also, samples were collected on closed-face matched weight cassettes. On 16 January 1987, removal of aircraft components and site clean-up operations was conducted. A crane was used to turn over the fuselage during recovery of the debris. Air sampling was obtained during these activities.

d. A Naval Medical Command Industrial Hygienist conducted sampling at the 13 July 1988 mishap of an AV-8B Harrier II stationed at Marine Corps Air Station, Cherry Point, North Carolina.[3] The aircraft suffered a systems failure and crashed a few miles from the runway in a small clearing. NIOSH Method 7400 was used with 0.8 µm mixed cellulose ester filters (MCEFs) in 25-mm cassettes open-faced collection mode with electrostatic extension cowls. DuPont P2500A and P2500B personal sampling pumps were used at 1.9-2.1 liters per minute.

Area samples were collected on the first day after the crash. Fixative was applied to large areas of damaged composite before clean up began. Area and personal samples were taken from 14-18 July during debris removal and site cleanup. On the second day after the crash, there was rigorous handling of debris with personnel movement through the area and some hand searching. Breathing zone samples were obtained from marines actively tearing apart main pieces of debris by hand while searching for electronic parts. The third day after the mishap, shovels and rakes were used to remove contaminated soil. Also, personnel continued moving, stacking, and loading large parts onto a flatbed for wrapping. Moving and shifting damaged composite material resulted in significantly higher airborne concentrations of fiber. However, applying fixative moderately reduced the generation of airborne fibers.

e. An F/A-18 aircraft crashed into an irrigation pipe located on the edge of an onion field and an adjacent barley field.[4] The F/A-18 is composed of 10% composite material. The aircraft mishap is estimated to have occurred in June 1988. The results from personal and area sampling accomplished after the AV-8B aircraft crash in 1987 were utilized as a basis for comparison of this F/A-18 incident. Both aircraft contain the same type of composite material, however, with different percentages (AV-8B has 26% and F/A-18 has 10%). A listing of the proper work practices and personal protective equipment is included in this letter as well as a respirator selection guide for carbon fibers. Air samples were collected during crash site clean-up and jet fuel removal operations. Samples were collected from the front of the tractor cab at the height of the driver's breathing zone. These samples were again taken using open-face, 37-mm cassettes with 0.8 um pore, mixed cellulose ester filters, using an air pump at 2 liters per minute during plowing operations in the morning and in the afternoon.

f. On 25 June1986, a Navy F-14 crashed in Dixie Valley, Nevada.[5] The F-14 presented potential exposures to boron composite material. This aircraft does not have published composite material weight or percentages by weight for the frame. Personnel from NAS Miramar, NAD Fallon, Naval Safety Center, Norfolk, and Naval Hospital, Oakland initiated the salvage operation. An on-site industrial hygienist provided observations, indicated potential problem areas, and provided recommendations based upon sampling results. Samples were collected from selected personnel working at the site during removal of aircraft debris and parts. Monitors were placed on the pit workers and the crane operator during salvage of the wreckage to determine personal exposures to airborne fibers and dusts. Airborne fiber concentrations were collected on 37-mm MCEF filters and were analyzed by the NIOSH 7400 fiber counting method. Preweighed 37-mm PVC filters were used to determine total particulate concentrations.

g. The Bioenvironmental Engineering Flight (BEF) at Luke AFB, Arizona, performed air monitoring at several mishap sites between 26 October 1998 and 26 March 1999.[6] The exact location of the aircraft mishaps are unknown; however, since the local BEF performed the sampling, it is assumed that the crash sites were proximate to Luke AFB. The F-16 has 4 different models and the average weight of composite material is approximately 200 pounds. The report encompasses sampling at four of six separate mishap sites. These four incidents were sampled since the remaining two sites revealed the aircraft structures were still intact. Personal air sampling was used to determine the crash recovery worker's exposure to potential inhalation hazards from composite fiber materials. Crash site operations included initial fixant spraying

over the debris, aggressive handling of materials by lifting, wrapping, loading, and final clean up. The initial spraying and parts movement involved spraying all exposed composite materials with a water wax solution. Wrapping included heavy plastic sheets and duct tape to cover and secure aircraft structures. A flat bed truck was used to load structures in preparation for disposal. Final clean up involved picking-up and bagging the remaining littered composite debris. Results from personal sampling indicated the concentrations of composite materials did not exceed Occupation Exposure Levels (OELs) for fibers (1fiber/cc).

h. The HAMMER Burn Study was conducted in September 2000 to simulate crash response and composite material mishap recovery activities.[7] The purpose was to determine the level of exposure to composites for personnel involved in mishap response operations. The Burn Study was performed at Tyndall AFB, FL, in a fire science hangar using large graphite/epoxy composite boxes. There were 3 composite material burns including: a small 20-pound piece cut out from wing box, the second was 316-pound composite box, and the last burn was 287-pound composite box. Air sampling consisted of both area and personal samples and quantified exposures for fibers, volatile organic compounds, phenol, particulates, and aromatic amines. Results of the industrial hygiene sampling were used for PPE recommendations listed in Table 3. A worst-case scenario was established by not applying aqueous film-forming foam (AFFF) to extinguish the JP-8 fire. A wax fixant was not applied to the composite boxes before handling by the recovery workers. All exposures were below AF OELs for the chemicals analyzed.

Table 1. Dust: Task and TWA Exposure Concentrations During Recovery Operations

| Aircraft | Crash Date | Fiber Type | Operation | Sample Type | Dust ($mg/m^3$) | | OEL ($mg/m^3$) |
|---|---|---|---|---|---|---|---|
| | | | | | Task | 8-hr. TWA | 8-hour |
| F/A-18 | 1989 | Graphite | Heavy equipment operator | total dust | NA | 15.9-18.3 | 15.0 |
| | | | Mishap Investigators | | NA | 24.1 | 15.0 |
| F-14 | 1986 | Boron | Crash pit work | total dust | 2.5-4.3 | 0.318-0.636 | 15.0 |
| F-16 | 1999 | Graphite | Spraying, pick-up, wrapping | inhalable | 0.046-1.324 | N/R | 10.0 |
| | | | | respirable | 0.053-0.785 | N/R | 3.0 |
| F-16 | 1998 | Graphite | Spraying, pick-up, wrapping | inhalable | 0.450-2.61 | N/R | 10.0 |
| | | | | respirable | 0.23-0.695 | N/R | 3.0 |
| F-16 | 1998 | Graphite | Spraying, pick-up, wrapping | inhalable | 0.059-1.11 | N/R | 10.0 |
| | | | | respirable | 0.012-0.36 | N/R | 3.0 |
| F-16 | 1999 | Graphite | Spraying, pick-up, wrapping | inhalable | 0.89-19.2 | N/R | 10.0 |
| | | | | respirable | 0.08-5.73 | N/R | 3.0 |
| Wing (crash simulation) | 2000 | Graphite | Simulated recovery, clean-up, cutting, wrapping | respirable | 0.0004-0.001* | 0.0001-0.0003* | 3.0 |
| | | | | total dust | 0.003-0.004* | 0.001-0.0012* | 15.0 |

(*)These results indicate average concentrations for the 3 composite burns

N/R – Not Reported

Table 2. Fiber: Task and TWA Exposure Concentrations During Recovery Operations

| Aircraft | Crash Date | Fiber Type | Operation | Fibers (f/cc) | | OEL (f/cc) | NIOSH Method |
|---|---|---|---|---|---|---|---|
| | | | | Task | 8-hr. TWA | 8-hour TWA | |
| F/A-18 | 1989 | Graphite | Heavy equipment operator | NA | <0.04-0.56 | 1.0 | 7400 |
| | | | Mishap Investigators | NA | <0.06 | 1.0 | 7400 |
| AV-8B | 1988 | Graphite | Hand searching debris | 3.67-6.142 | 0.206-0.345 | 1.0 | 7400 |
| | | | Heavy equipment operators | <0.03-2.865 | <0.005-0.161 | 1.0 | 7400 |
| | | | Handling/moving debris | <0.671-6.998 | <0.014-0.306 | 1.0 | 7400 |
| AV-8B | 1987 | Graphite | Digging, moving, collecting | <0.2-0.196 | <0.097 | 1.0 | N/R |
| | | | Components removal | 0.067-0.10 | 0.02-0.03 | 1.0 | N/R |
| | | | Crane operator | 0.017 | 0.004 | 1.0 | N/R |
| F/A-18 | 1988 | Graphite | Plowing | <0.005 | NA | 1.0 | 7400 |
| F-14 | 1986 | Boron | Heavy equipment operator | 0.02 | 0.0073 | 1.0 | 7400 |
| | | | Crash pit work | 0.02-0.06 | 0.0046-0.014 | 1.0 | 7400 |
| F-16 | 1999 | Graphite | Spraying, pick-up, wrapping | 0.0026-0.0135 | 0.0003-0.003 | 1.0 | 7400 |
| F-16 | 1998 | Graphite | Spraying, pick-up, wrapping | 0.0025-0.0191 | 0.00153-0.0127 | 1.0 | 7400 |
| F-16 | 1998 | Graphite | Spraying, pick-up, wrapping | 0.0013-0.0042 | 0.00025-0.00075 | 1.0 | 7400 |
| Composite wing (crash simulation) | 2000 | Graphite | Simulated recovery, clean-up, cutting, wrapping | 0.0743-0.4831* | 0.0248-0.1610* | 1.0 | 7402 |

N/R – Not Reported

(*) These results indicate average concentrations for the three composite burns.

## V COMPOSITE HAZARD ASSESSMENT

a. At each crash site a composite material risk assessment should be conducted. The assessment should occur after the crash site is deemed safe for entry by the Fire Department, EOD, and Fuels personnel (Hydrazine). The site should be categorized as posing a high or low composite material exposure risk. The assessment should take into consideration the following parameters:

1. Visual assessment. A visual assessment of the composite material should include the following:

a) Identification and location of composite materials. Resources include TO 00-105E-9, *Aircraft Emergency Rescue Information (Fire Protection)*, weapon system specific TOs (also known as the –3s), weapon systems maintenance personnel and crew chiefs, Crash Recovery Team (also called Carbon Fiber Teams).

b) Nature and extent of damage. Is the composite material spread throughout the crash site? Has the material been subjected to both physical damage and fire?

2. Duration and location of fire. A fire increases the risk to composite dust/fiber exposure because the resin will burn off leaving the fiber exposed. This material can easily become airborne if disturbed and may also be spread throughout the site depending on the conditions of the crash. An extended fire increases the fiber/dust risk. The quantity of fuel is also a key factor when assessing fire duration. The aircraft fire will not be evenly distributed; rather, there will be a gradation of fire damage for the various aircraft parts. If the composite components receive no/very little fire damage the risk is minimized.

3. Physical damage. If the aircraft composite materials are physically damaged, the risk of exposure is increased. If the composite material is primarily in the rear of the aircraft (stabilizers) and they are intact with little to no damage, the risk is lower.

4. Aircraft type/Quantity of Composite Material. Some aircraft should automatically be put into the high-risk category due to the high percentage or high quantity of composite materials. For example the B-2, F-22, V-22 Ospry, and Joint Services Fighter (JSF) would fall into this category.

5. Terrain and environmental conditions. Planes have crashed into mountains, oceans, and deserts. A plane that crashes into swampland will present a lower composite dust risk than one that crashes into a hot, dry desert. Another factor to consider is wind. Both wind speed and direction may affect the risk category. A high wind speed may carry dust fiber away from the site that could reduce the dust/fiber concentrations at the site.

6. Phase of Response/Recovery. As a general rule, early into the response, the risk should be assumed high and downgraded after appropriate assessment and controls have been employed. The use of PPE alone cannot permit a site to be downgraded.

7. Type of crash. The two significant factors that should be considered are speed of the aircraft and angle of impact. A low speed crash, which may occur during a takeoff, will result in crash debris being relatively confined within the immediate impact point. The site debris will be further confined as the angle of impact increases. The crash site that will have the greatest dispersion of debris will occur when the incident is a high speed, low impact angle mishap.

8. Additional information for behavior of composite materials during a crash can be obtained from the USAF Advanced Composites Office located at Hill AFB (DSN 586-3318) http://www.hill.af.mil/aco/index.html.

## VI RISK MITIGATION MEASURES

a. Spraying the composite material with a fixant (polyacrylic acid) is recommended to minimize further release and resuspension of composite dusts. The fixant should be reapplied whenever the materials are disturbed. The fixant only provides a surface coating that can easily become ineffective as a control measure once the coating is disturbed. **Permission to spray fixant should be granted by the Board President member from the Interim or Permanent Investigating Board.** In certain circumstances, spraying fixant may interfere with the analysis of evidence. The investigative effort is always the priority at the crash site. From a risk assessment perspective, if fixant cannot be sprayed then a crash site will remain in a "high-risk" category. The control measures are then implemented through the use of personal protective equipment.

b. Another effective control measure is to wrap the identified composite materials in plastic. The recommended material is plastic sheeting/film or plastic bags with a minimum thickness of 6 mils (0.006 inches). The requirement of asking the Board President as stated above applies.

c. An additional control measure can be the establishment of zones. The zones would delineate PPE requirements whenever personnel performed work while within a given radius of the damaged composite material. This control requirement will be only be effective if the damaged composite material is restricted to well-defined areas within the crash site.

d. Minimize the number of people at the site.

## VII PERSONAL PROTECTIVE EQUIPMENT

a. PPE selection must be based on two factors: the task being performed and the composite material exposure category. Other hazards may also drive PPE requirements. Table 3 outlines the minimum recommended PPE requirements during the recovery phase. The risk assessment task involves an initial composite material hazard assessment. The Crash Recovery Team, maintenance personnel, BEE, and a Safety Board representative should accomplish this assessment. As necessary, the health and safety representative can always require a higher level of protection. The respiratory protection is always the controversial aspect of PPE recommendations. Personnel wearing any respirator other than a filtering facepiece device must meet all the program requirements such as: medical clearance, written program, training in the

use, maintenance, and storage of respirators, fit-testing, etc. See AFOSH 48-137 *Respiratory Protection Program* for additional guidance.

b. The use of gloves at a crash site is straightforward. Leather gloves (outer) with nitrile rubber (inner) should be worn whenever crash debris is handled. The leather gloves provide protection from physical hazards such as sharp objects. It is important to remember that certain fibers (boron- F-15) will easily penetrate the gloves and skin. Extra precaution should be taken when handling these materials. The inner nitrile rubber gloves are required to prevent exposure to liquids such as: jet fuel, hydraulic fluid, biological fluids, etc.

c. Disposable Tyvek® coveralls should be worn whenever the risk is high or when the risk is low but the material is being disturbed due to either handling or environmental considerations (i.e. wind). Coveralls will prevent skin exposure. Eye protection should be worn whenever material is being disturbed such that the material becomes airborne. In many cases, the use of the full-face respirator is advised so that both the inhalation and eye hazards are controlled.

Table 3. Follow-On Response

| | | Personal Protective Equipment | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Low Risk | | | | High Risk | | | |
| **Specialty** | **Activity/Task** | Disposable Coveralls | Gloves[1] | Eyes | Respirator | Disposable Coveralls | Gloves[1] | Eyes | Respirator |
| Composite Fiber or Crash Recovery Team | 1. Risk Assessment -spray fixant -wrap material | X | X | | (Assume high) FF APR[2] | X | X | | FF APR |
| BEE | 1. Risk assessment | X | X | | (Assume high) FF APR | X | X | | FF APR |
| | 2. Sampling (not entering site) | | X | | None | X | X | | None |
| Services (Mortuary Affairs) | Recovery of bodies/parts | X | X | | Dust Mask (FFPD) | X | X | | Dust mask (FFPD)[3] |
| Initial/Permanent Safety Inspection Board | 1. Preserve Evidence 2. Identify & tag parts -light movement | | X | | None | X | X | | Dust mask (FFPD) |
| Aircraft Recovery | 1. Package/Remove aircraft -light handling | | X | | None | X | X | | Dust mask (FFPD) |
| | 2. Aggressive handling (sawing, shredding) | X | X | X | FF APR (for eye protection) | X | X | X | FF APR |

X- indicates PPE required

Boots: Boots shall have steel toes. If Boron Composite fibers are present, steel shank is also required. Disposable or rubber overboots are preferable for decontamination purposes.

1- Leather outer gloves, nitrile rubber inner glove

2- Full Face Air-purifying (FF APR)  3- Filtering Facepiece Device (FFPD)

## VIII AIR SAMPLING

a. A historical review of sampling efforts, and the recent composite material combustion byproduct study[8] indicates single fiber concentrations are very low. Therefore, exposure efforts should be more focused on particulate matter. Higher concentrations of nonfibrous particles and fiber clumps may be detected. If fibers sampling is conducted then NIOSH Method 7400 *Asbestos and Other Fibers by Phase Contrast Microscopy (PCM)* should be used. This method counts **all** fibers that meet the established criteria (i.e., length, width, aspect ratio). It is an acceptable method since we can assume all of the fibers collected are from composite material. Additionally, this analytical method is less expensive than NISOH Method 7402. NIOSH Method 7402 was used during the HAMMER burn study because there was a need to confirm fiber types and to evaluate fiber size characteristics. The following summarizes lessons learned regarding NIOSH Method 7402.

(1) During the preparation steps of NIOSH Method 7402 *Asbestos by Transmission Electron Microscopy* (TEM), there may be a gain or loss of fibers. The loss of fibers can occur during the ashing/etching phase. The ashing/etching step strips the top layer of the filter to expose small fibers embedded in the filter. Fibers on the surface may be oxidized or reduced in diameter because of the conditions during etching. Fiber counts can also be artificially increased during the redeposition phase. During this phase portions of the filter are placed in glass bottles and rinsed off with water. The solution is then ultra-sonicated which tends to break up fiber clumps into individual fibers. Generally speaking fiber clumps will not be respirable; therefore by breaking individual fibers loose, the respirable fiber concentration can be positively biased.[9] The clearing step which is required for both NIOSH methods involves exposing the filter to a solvent such as dimethyl formamide. This step collapses the filter from a thickness of 60 μm to 15 μm. This step should not affect the fiber counts.

(2) Also during NIOSH Methods 7402 and 7400, some of the fibers may be collected on the wall of the cowl, because all particles have a charge. There are different interpretations as to the health significance of the deposited fibers. The NIOSH position is that if the material deposited on the wall, it would not have been inhaled; therefore, do not make any effort to remove these fibers for subsequent analysis. The primary purpose of the cowl is to protect the filter and the deposited fibers are not relevant.

b. Tables 4 and 5 provide the recommended contaminants that should be sampled during crash site operations. These other contaminants should be sampled following the indicated methods. Background samples should be taken upwind to quantify the contribution of particulate material from natural sources.

Table 4. Air Sampling Methods – Particulate/Fiber

| Contaminant | NIOSH Method | Media | Flow Rate | Equipment |
|---|---|---|---|---|
| Fibers | 7400 Phase Contrast Microscopy | 25mm, 0.8-um MCE Filter Conductive Cowl | 2 lpm | Sample Pump, Tubing, Calibration Unit, 2-10 Blanks |
| Inhalable Particulates | None | 37mm or 25 mm, 5-um, PVC Filter | 1 – 2 lpm | Inhalable sampler, Sample Pump, Tubing, Calibration Unit, 2-10 Blanks |
| Respirable Particulates | 0600 Particulates Not Otherwise Regulated | 37 mm, 5-um PVC Filter | Follow directions for specific Cyclone (i.e. Gilian Cyclone 1.7 lpm) | Cyclone, Sample Pump, Tubing, Calibration Unit (must calibrate with cyclone), 2-10 Blanks |

Table 5. Air Sampling Methods – Organics/Acid gas

| Contaminant | NIOSH Method | Media | Flow Rate | Equipment |
|---|---|---|---|---|
| Polynuclear Aromatic Hydrocarbons | Gas Chromotography 5515 | Filter and Sorbent: 2-um, 37mm PTFE Filter (brown cassette) & XAD Tube | 2 lpm | Sample pump, tubing, calibrator, 2-10 cassette blank, and XAD-2 blanks, and 8 replicates on pre-weighed filters for solvent selection Note: wrap sampling train with foil to prevent UV interference and ship at 0 degree C |
| Aromatic Amines | 2002 | Silica Gel Sorbent Tube (150/75mg) | 0.02 – 0.2 lpm | Sample pump, tubing, calibrator, 2-10 blanks |
| Hydrogen Cyanide | 6010 | Soda Lime Solid Sorbent Tube (600/200mg) | 0.05-0.2 lpm | See above |
| Cresol (all isomers) Phenol | 2546 | XAD-7 Solid Sorbent Tube (100/50mg) | 0.01-0.1 lpm | See above |

## IX OTHER POTENTIAL HAZARDS

a. Aircraft crash sites are littered with numerous potential hazards. The types of hazards vary depending on the type of aircraft, whether or not casualties were involved, type of cargo, and whether or not fire was involved, etc. If a fire was involved, toxic substances will be released. Potential contaminants/hazards are jet fuel, unexploded ordinance, isocyanates, blood borne pathogens, radioactive material, plastics, polymers comprised of organic material and composite fibers. Aircraft structural alloys include but not limited to beryllium, aluminum, zinc, hydrazine (F-16), magnesium, titanium, and copper released in the form of metallic oxides, which pose an inhalation hazard to unprotected responders. Potential exposure to the civilian population depends upon their proximity to the crash site. According to Stuart R Culling, Senior Inspector of Accidents, "The main problem that we face is identifying the chemicals likely to be present after a ground fire. It is difficult enough to obtain information about what is built into an aircraft, never mind what is likely to happen to it in a fire."[10]

b. Headquarters Air Force Civil Engineer Support Agency's Fire Protection Division compiled data and developed an AF Technical Order. The T.O. identifier is T.O. 00-105E-9 and is titled "Aircraft Emergency Rescue Information (Fire Protection)" and is located at URL http://137.244.215.33/ti/tilta/documents/to00-105E-9.htm. The types of aerospace vehicles included in this document are U.S. fighter, cargo and bomber aircraft, helicopters, NATO aircraft and helicopters, commercial airliners, and the Space Shuttle. This T.O. should prove invaluable as tool to develop emergency response guidance for first responders and identify hazards associated with post-crash activities.

c. In addition to providing hazard information, the T.O. also provides illustrations, which assist in locating and identifying various components of each aircraft. The following illustrations show the exterior composition of a USAF F-117 fighter aircraft.

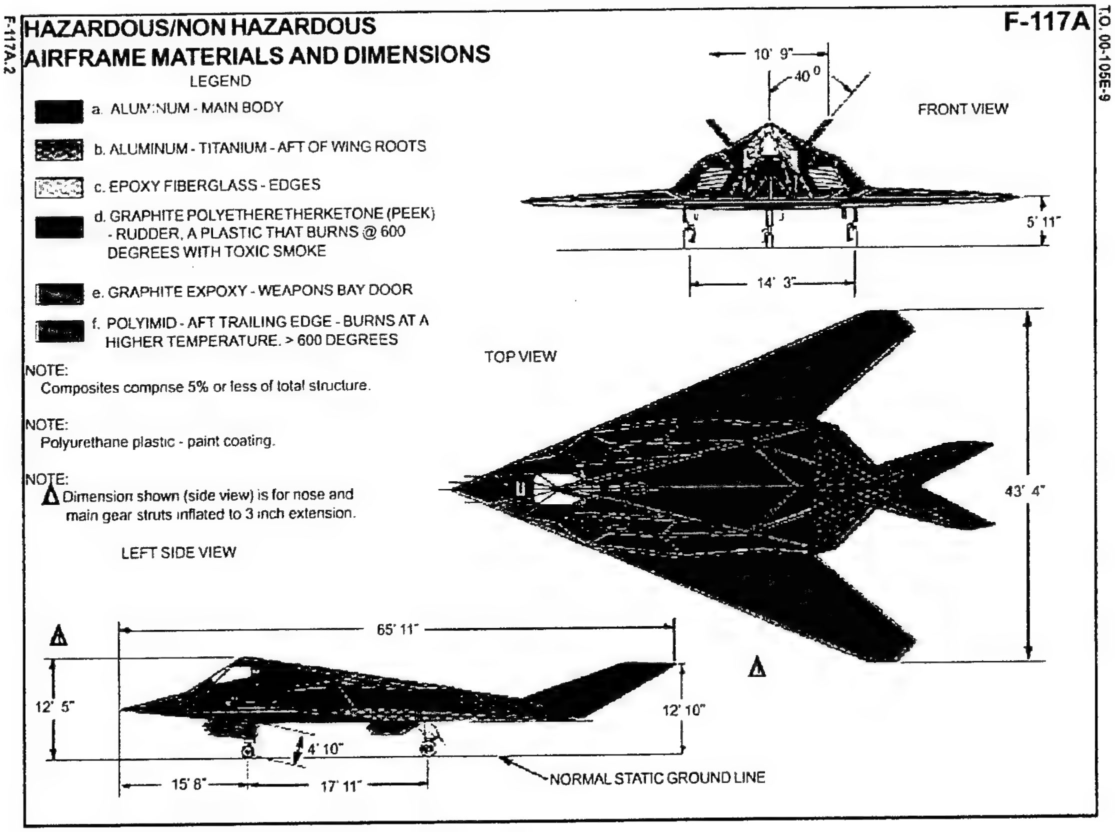



Figure 1. F-117A Hazardous/Nonhazardous Airframe Materials

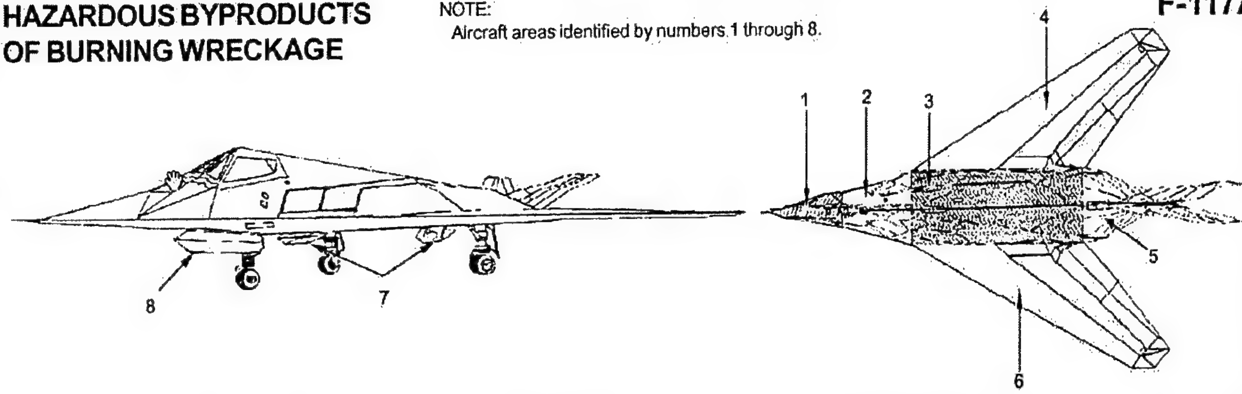
**Note**: Though the illustration seems to indicate that the amount of composites material currently used on the F-117 exterior is relatively small, the USAF F-117 Systems Program Office stated that the amount of composite is slightly less than 2000 lbs. This is relatively small in comparison to a C-17's 15,000 lbs, but its hazard potential should be factored in nonetheless.

The following illustrations describe the hazardous by-products potentially released during a fire involving an F-117 aircraft. This is an example of the type of information contained within T.O. 00-105E-9.

## HAZARDOUS BYPRODUCTS OF BURNING WRECKAGE

NOTE:
Aircraft areas identified by numbers 1 through 8.

**F-117A**




| GENERAL MATERIAL | SPECIFIC MATERIAL | AREA USED ON AIRCRAFT | BYPRODUCT |
|---|---|---|---|
| Fuel<br>Hydraulic fluids<br>Lubricants | Fuel, JP8<br>Oil, low temperature<br><br>Oil, synthetic<br>Molybdenum disulfide<br>Grease, various types<br>Fluid, hydraulic, various types | 3,4,5,6,7,8 | Carbon monoxide<br>Carbon dioxide<br>Sulfur oxides<br>Polynuclear aromatic hydrocarbons<br>Phosphorus oxides |
| Rubber (gaskets and tires)<br><br>Honey comb core<br>Plastics (gaskets, sleeving, electrical and thermal insulations, tubing, canopy, sheets, and parts | Neoprene<br>Chloroprene<br>Silicones<br>Fluorosilicones<br>Nitriles<br>Polyvinyl chloride<br>Nylons<br>Polyolefins<br>Teflons<br>Polyurethanes<br>Acrylic - polycarbonate<br>Viton, Phenolics, Bismaleimides, Epoxies, and Polysulfide | Throughout aircraft | Carbon monoxide<br>Carbon dioxide<br>Polynuclear aromatic hydrocarbons<br>Hydrochloric acid<br>Hydrofluoric acid<br>Nitrogen oxides<br>Hydrogen cyanide<br>Phosgene<br>Formaldehyde<br>Sulfur oxides |

Figure 2. F-117A Hazardous Byproducts

## HAZARDOUS BYPRODUCTS OF BURNING WRECKAGE-Continued

**F-117A**

| GENERAL MATERIAL | SPECIFIC MATERIAL | AREA USED ON AIRCRAFT | BYPRODUCT |
|---|---|---|---|
| Fabrics and fibers, natural and synthetic | Wool<br>Kevlar<br>Carbon fibers - epoxy coated<br>Glass fibers - aramid, epoxy, teflon, and polyester coated<br>Polyetherether ketone<br>Polysulfide<br>Cellulose | 1,2,3,4,5,6 | Hydrogen cyanide<br>Nitrogen oxides<br>Sulfur oxides<br>Carbon monoxide<br>Carbon dioxide<br>Polynuclear aromatic hydrocarbons<br>Hydrochloric acid<br>Hydrofluoric acid<br>Phosgene<br>Formaldehyde |
| Metal alloys - structural, fillers, bonding, and welding | Aluminum, Chrome, Copper, Gold, Iron, Steel, Lead, Silver, Tin, Titanium, Zinc, and Trace metals | Throughout aircraft | All may melt and resolidify. No hazardous emissions. |
| Blanket insulation and other ceramics | Fiberfrax, Fused ceramic powders | 1,3,5 | None |
| Adhesives<br>Sealants<br>Paint<br>Coatings | Polysulfides<br>Silicones<br>Flourosilicones<br>Epoxy<br>Polyurethane<br>Buena - N<br>Iron<br>Silver<br>Silicon dioxide<br>Strontium chromate<br>Lead chromate | Throughout aircraft | Hydrogen cyanide<br>Nitrogen oxides<br>Sulfur oxides<br>Carbon monoxide<br>Carbon dioxide<br>Polynuclear aromatic hydrocarbons<br>Hydrochloric acid<br>Hydrofluoric acid<br>Phosgene<br>Formaldehyde |

Figure 2. F-117A Hazardous Byproducts (Continued)

**Note:** AFIERA also produced an aircraft mishap emergency response guide template, which can be found at: https://www.afms.mil/iera/rsh/IndustrialHygiene/Aircraft_Mishap_Response_Plan.PDF. This document may be helpful in developing a base specific crash response program. This product was developed using various documents and guidance from numerous bases and organizations worldwide.
Wright-Patterson AFB also maintains a database on aircraft radioactive material located at http://www.abwem.wpafb.af.mil/em_coldfusion/emb/aircraft/with_rad.cfm

Table 6. General Aircraft Mishap Related Hazardous Materials Concerns

| Hazardous Material | Physical Description | Health Hazard | Aircraft | Quantity/Location |
|---|---|---|---|---|
| Hydrazine | Clear, oily, liquid with an odor similar to ammonia; combustible and explosive | Can cause severe local damage or burns with contact to skin and eyes. If inhaled, vapor causes local irritation to eyes and respiratory tract and systemic effects | F-16 | 6.8 gallons |
| Beryllium | Dust or powder form silvery and resembling aluminum powder | Toxic respiratory and eye irritant; if introduced under skins through cuts or punctures, slow-healing ulcers may develop | C-5, F-100, A-7D | C-5 Brake pads, F-100 wing tip area and around cockpit; and the A-7D landing gear bushings |
| Triethyl-borane | Extremely toxic and volatile liquid with a sweet pungent odor | Contact with skin or eyes will cause deep thermal burns | SR-71 | 700cc, Upper left side of each engine |
| Lithium Thionyl Chloride | Soft, silvery highly reactive metallic element | Reacts violently with H2O, serious injury to personnel can occur if incorrect fire suppression procedures are ignored | C-17 | Used in on-board computer batteries |
| Pressurized tanks/acft parts | Compressed liquids and gases (oxygen), tires | Physical/chemical hazards from projectiles, release of materials | All | Interior/exterior |
| Strontium | Radioactive material used in aircraft construction | Internal and external hazard; Beta radiation dose reduce 10% by wearing leather gloves | Helicopters | Anti-ice detectors and blade integrity indicators |
| Depleted Uranium (DU) | Radioactive heavy metal used as a ballast or counterweights in aircraft gyroscopes, flight controls, helicopter blades, and aileron balances; chemical and radiation hazard | Inhalation is the most significant mode of entry; If involved in fire, DU will release very toxic fumes depositing in the respiratory tract then taken into the blood stream and deposited in internal organs. This allows intense ionization by the alpha particles resulting in severe localized damage to cells. | A-7 | 2 weights, One in cockpit and one in lower part of vertical stabilized |
| | | | A-10 | 30mm Ammo |
| | | | C-5 | One on left and right ailerons and five on left and right elevators |
| | | | C-130 | Ailerons, elevators, ad rudder |
| | | | C-141 | Left and right ailerons<br>46 weights on left and right elevators |
| | | | F-16 | Gun pods on certain models |

**X SORTING OUT WRECKAGE:** The aircraft wreckage must be kept in storage for one year after the mishap. The material must be available to mishap investigators for follow-up analysis. Materials are wrapped in plastic to prevent potential exposures if they are disturbed. The wreckage should be sorted by systems and/or materials such as avionics, hydraulics, and composites, etc. If the material is not sorted initially, then all the materials will have to be handled again (potentially causing unnecessary exposures). DRMO requires that similar materials be packaged together for disposal. Labeled crates brought out to the crash site for recovery will aid in storage and disposal procedures of the wreckage.

**XI HAZARDOUS WASTE**

a. Burned composite material has been tested for disposition purposes. Tests for organics, inorganics, and metals have typically shown no detectable levels.

b. Additional guidance may be found in the following:

1. DRMS-I 4160.14, Volume II, Chapter 4, paragraph 18, "Composite Fiber Property," 19 June 2000

2. DoD 4160.21-M, Chapter 5, "Carbon Composite Fiber Material," August 1997.

c. The material must be demilitarized as follows:

1. Treated with a fixative (water and floor wax solution).

2. Bagged in durable plastic or covered with shrink wrap.

3. Sealed and labeled appropriately prior to disposal.

## References


1. Mahar, Sean. "Particulate Exposures Resulting from the Investigation and Remediation of a Crash Site of an Aircraft Containing Carbon Composites." *American Industrial Hygiene Association Journal.* 51(9): 459-461 (1990).

2. Memorandum from Commanding Officer, Naval Hospital to Commander, Carrier Airwing Reserve 30, Industrial Hygiene Assist at Dixie Valley F-14 Crash Site, 25 June 1986.

3. Industrial Hygiene Survey Report for AV-8B Mishap, Marine Corps Air Station, Cherry Point, NC, Navy Environmental Health Center.

4. Memorandum from Commanding Officer, Navy Environmental Health Center to Commander, Light Attack Wing answering the request for advisory opinion concerning the crash of an F/A-18 aircraft into an onion field.

5. Formisano, Jerry A. "Composite Fiber Field Study: An Evaluation of Potential Personnel Exposures to Carbon fibers During the Investigation of a Military Aircraft Crash Site." Engineering Controls and Work Practices. 267-275.

6. Memorandum for AFIERA/RSHI from 56 AMDS/SGPB, Aircraft Mishap Composite Fibers Air Sampling Results.

7. Hazardous Aerospace Materials Mishap Emergency Response (HAMMER) Integrated Product Team (IPT) Burn Study (September 2000).

8. Kimmel, E.C., et al, "Airway Reactivity Response to Advanced Composite Material (ACM) Combustion Atmospheres: B2-ACM" Naval Health Research Center Detachment (2000).

9. *Aerosol Measurement: Principles of Technique and Applications.* Edited by Klaus Willeke and Paul A. Baron (1993).

10. Culling, Stuart R., "Aircraft Wreckage – A Potential Hazard to Health", *Forum*, Published by the International Society of Air Safety Investigators, Volume 25, No 4, November 1992

## APPENDIX A

Aircraft Composite Material Locations

| Aircraft | Location | Composite Fiber/Matrix * | | | | |
|---|---|---|---|---|---|---|
| | | B/EP | GL/EP | AR/EP | GR/EP | GR/BMI |
| A-10 | Leading Edges | | | x | x | |
| AV-8 | Flap | | | | | x |
| | Gunpack | | | | | x |
| | Horizontal Stabs | | | | x | |
| | Nosecone | | | | x | |
| | Rudder | | | | x | |
| | Wing Skin | | | | x | |
| B-1 | Ailerons | | | | x | |
| | Fairings | | | | x | |
| | Longeron | x | | | | |
| | Weapons Bay Doors | | | | x | |
| B-2 | Control Surfaces | | | | x | |
| | Ducting | | | | x | |
| | Leading Edges | | | | x | |
| | Trailing Edges | | | | x | |
| | Wing Skins/Substructure | | | | x | |
| C-5 | Radome | | x | | | |
| C-17 | Ailerons | | | | x | |
| | Fillets | | | | x | |
| | Landing Gear Doors | | | | x | |
| | Leading Edges | | | | x | |
| | Nacelle Doors | | | | x | |
| | Radome | | x | | | |
| | Rudders | | | | x | |
| | Spoilers | | | | x | |
| | Stabilizer | | | | x | |
| | Trailing Edges | | | | x | |
| | Wing Fuselage | | | | x | |
| | Wing Trailing Edges | | | | x | |
| | Winglets | | | | x | |
| C-130 | Radome | | x | | | |
| C-141 | Radome | | x | | | |
| | Wing Substructure | x | | | | |

*B/EP = Boron/Epoxy
GL/EP = Fiberglass/Epoxy
AR/EP = Aramid/Epoxy
GR/EP = Graphite/Epoxy
GR/BMI = Graphite/Bismaleimide

| Aircraft | Location | Composite Fiber/Matrix* | | | | |
|---|---|---|---|---|---|---|
| | | B/EP | GL/EP | AR/EP | GR/EP | GR/BMI |
| F-14 | Horizontal Stabilzer | x | | | | |
| | Vertical Stabilizer | x | | | | |
| F-15 | Horizontal Stabilizer | x | | | | |
| | Speed Brake | | | | x | |
| | Vertical Stabilizer | x | | | | |
| F-16 | Horizontal Stabilizer | | | | x | |
| | Vertical Stabilizer | | | | x | |
| F-18 | Dorsal Covers | | | | x | |
| | Horizontal Stabilizer | | | | x | |
| | Vertical Stabilizer | | | | x | |
| | Wing Skin | | | | x | |
| F-22 | Edges | | x | | | x |
| | Outer Skin | | | | | x |
| F-117 | Edges | | x | | | x |
| | Rudders | | | | x | |
| | Weapons Bay Door | | | | x | |
| HH-60 | Cockpit Surface | | | x | | |
| | Main body | | | | x | |
| | Rotor Blades | | | | | |
| KC-10 | Radome | | x | | | |
| KC-135 | Radome | | x | | | |
| T-3 | Cockpit Surface | | | | x | |
| | Surface/Substructure | | x | | | |
| V-22 | Wetted Surface | | | | x | |

*B/EP = Boron/Epoxy
GL/EP = Fiberglass/Epoxy
AR/EP = Aramid/Epoxy
GR/EP = Graphite/Epoxy
GR/BMI = Graphite/Bismaleimide

# APPENDIX B

### Bioenvironmental Engineering Flight Checklist
### Response to Aircraft Mishaps Involving Composite Materials

1. Have wind direction and speed been recorded?

2. Has an entry control point been established? Where can contaminated protective gear be removed?

3. Has EOD declared the area safe for entry by other teams?

4. Have downwind areas been notified to keep windows/doors shut and remain indoors if not evacuated due to fire and smoke plume?

5. Have helicopters been restricted from the area to avoid fiber and dust re-suspension?

6. Have potential composite material locations been identified? (contact Structural Maintenance personnel, the T.O. manager, or the Item Manager, or review the specific weapon specific technical orders)

7. Have other hazards been identified, such as large quantities of spilled jet fuel or location of radioactive parts, such as depleted uranium?

8. Are HEPA vacuums available if parts, equipment, or protective equipment need decontamination? (HEPA vacuum is the best method to remove residual dusts; possible sources are the Asbestos Removal Team and Structural Maintenance)

9. Is the entry control point controlled for contaminated personnel? Are protective garments removed before passing through? Reusable PPE (gloves, boots) should be decontaminated with a HEPA vacuum.

10. Has an on-site assessment been made of the quantity of exposed composite materials?

11. Are Bioenvironmental Engineering personnel properly outfitted with protective equipment?

12. Are initial site entry teams outfitted with the proper protective equipment? (SCBA, fire-fighting suits)

13. Are recovery site entry teams outfitted with the proper protective equipment? (air-purifying respirator with N100 filters, Disposable suit with hood, inner nitrile/outer leather gloves, steel toe work boots [steel shank if boron fibers present], safety goggles).

14. Are entry teams briefed on potential hazards?

15. Are the following sampling equipment and supplies available?

a. Air sampling pumps
b. Air flow calibrator
c. Respirable dust cyclones
d. Total dust samplers
e. Analytical balance with 1ug sensitivity (possible locations: PMEL, Fuels Laboratory)
f. 5-um polyvinyl chloride (PVC) filters in 37-mm cassettes
g. 0.8-um mixed cellulose ester (MCE) filters in 25-mm cassettes with black anti-static cowling
h. Tygon/rubber tubing
i. Tripod or mounting stand for area samples
j. NIOSH Manual of Analytical Methods: Methods 0600, 0500, and 7400

16. Are sampling pumps calibrated, media attached, and pumps placed on the most likely exposed workers?

17. Are area samplers placed 2000 feet upwind in a representative area?

18. Have aircraft parts cooled and a fixant (such as floor wax) been sprayed on exposed, suspected composite material parts? (this may be delayed or ruled inappropriate by aircraft crash investigators based upon their needs and requirements; plastic sheeting may also be used to control spread of fibers and dust)

19. Has a soil tackifier been applied if necessary?

20. Is eating and drinking restricted from the site?

21. Have workers been told to shower at the earliest opportunity to wash off any residual fibers?

22. Has a listing of response personnel been assembled in the event medical monitoring is needed?

23. Are all areas known to be contaminated with composite fibers adequately cleaned?

24. Have waste disposal procedures for waste generated during recovery been coordinated with Civil Engineering?